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12 February 1992

ORIGINAL: ENGLISH

COMMITTEE ON THE PEACEFUL
USES OF OUTER SPACE

REPORT OF THE EUROPEAN SPACE AGENCY

Note by the Secretariat

The European Space Agency (ESA) has submitted the attached report 1/ on its activities during the year 1990 for the information of the Committee on the Peaceful Uses of Outer Space. The report is available in English only.

Notes

1/ In view of the limited number of copies received, the report is distributed to the members of the Committee only.

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COMMITTEE ON THE PEACEFUL
USES OF OUTER SPACE

WMO TROPICAL CYCLONE PROGRAMME: REPORT BY THE WORLD METEOROLOGICAL ORGANIZATION

Note by the Secretariat

The World Meteorological Organization (WMO) has submitted the attached report 1/ on its tropical cyclone programme, covering the period 1 July 1990 to 30 June 1991, for the information of the Committee on the Peaceful Uses of Outer Space. The report has been prepared in English, French, Russian and Spanish.

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COMMITTEE ON THE PEACEFUL
USES OF OUTER SPACE

REPORT OF THE INTERNATIONAL TELECOMMUNICATIONS SATELLITE ORGANIZATION

Note by the Secretariat

The International Telecommunications Satellite Organization (INTELSAT) has submitted the attached report, 1/ covering the period April 1990-April 1991, for the information of the Committee on the Peaceful Uses of Outer Space. It has been prepared in English, French and Spanish.

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COMMITTEE ON THE PEACEFUL
USES OF OUTER SPACE

REPORT OF THE EUROPEAN TELECOMMUNICATIONS SATELLITE ORGANIZATION

Note by the Secretariat

The European Telecommunications Satellite Organization (EUTELSAT) has submitted the attached report 1/ on its activities during the year 1990 for the information of the Committee on the Peaceful Uses of Outer Space. The report has been prepared in English and French.

Notes

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COMMITTEE ON THE PEACEFUL USES
OF OUTER SPACE

NATIONAL RESEARCH ON THE QUESTION OF SPACE DEBRIS

Note by the Secretariat

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1. In paragraph 24 of resolution 46/45 of 9 December 1991, the General Assembly considered that it was essential that Member States pay more attention to the problem of collisions with space debris and other aspects of space debris, and called for the continuation of national research on this question, for the development of improved technology for the monitoring of space debris and for the compilation and dissemination of data on space debris. To the extent possible, the Assembly noted, information thereon should be provided to the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space in order to allow it to follow this area more closely.

2. The General Assembly, in paragraph 25 of the same resolution, requested the Secretary-General to invite Member States to provide information on their national research on space debris to the Subcommittee.

3. The Secretary-General addressed a note verbale dated 11 December 1991 to all Member States, inviting them to communicate to the Secretariat, by 31 January 1992, the information requested above so that the Secretariat could prepare a report containing this information for submission to the Subcommittee at its twenty-ninth session.

4. The present document was prepared by the Secretariat on the basis of information received from Member States as of 5 February 1992. Information received subsequent to that date will be included in addenda to the present document.

AUSTRALIA

[Original: English]

AUSTRALIAN RESEARCH ON SPACE DEBRIS

Introduction

National research on space debris in Australia is carried out in two distinct fronts, first, through two commercial companies, Spaceguard Pty. Ltd. and SODA Pty. Ltd., and secondly, through the University of Adelaide. Both areas receive funding from the Australian Government.

Current Australian research activities in the space debris field are as follows.

1. Impact modelling

The probabilities, impact angles and velocities upon different faces of a satellite by space debris may be calculated using a suite of programs developed by Spaceguard Pty. Ltd./SODA Pty. Ltd. These programs make use of the input satellite orbit, orientation and facial areas, the known (tracked by

US SPACECOM) space debris population (sizes over 10 cm), and state-of-the-art models of the distribution of smaller debris (sizes below 10 cm) based upon all known fragmentation events.

The results of such calculations allow the damage potential for each face of a satellite to be determined: for example, the perforation rate through a satellite skin, or the shielding required. These results are of use in a variety of situations, such as:

- Satellite engineering design;
- Shielding design by buffers around larger structures such as the planned Space Station;
- Insurance premium assessments considering the risk posed to commercial satellites;
- Laboratory studies of impacts.

This work into space debris is being financed through a number of Government agencies, including grants under the Australian Government's industrial research and development scheme.

Spaceguard Pty. Ltd. and SODA Software Pty. Ltd. were set up in order to service a perceived market concerned with the international satellite insurance industry. These companies are dedicated to providing hazard assessments for satellites under the threat of impacts by man-made debris and natural meteoroids. Spaceguard is able to provide a hazard assessment for specific satellites (i.e., the computations take into account its orbit, size, orientation and so on).

2. Analysis of returned spacecraft samples

In January 1990, the Long Duration Exposure Facility was returned to Earth with the Space Shuttle after five years in orbit. One of the most important space debris-meteoroid impact experiments on board was the set of exposure plates designed and operated by the teams at the Unit for Space Sciences of the University of Kent.

Spaceguard Pty. Ltd. and the Anglo-Australian Observatory are involved in the analysis of these data. Australian involvement stems from software developed which allows the calculation of the impact probability, velocity and trajectory upon each face for objectives in stipulated geocentric orbits (i.e., space debris). This project is receiving funding from the Australian Research Council and the British Science and Engineering Research Council.

3. Radar observations of small infalling debris

The hazard posed by debris is dominated by the particles in the 1 mm-1 cm range, and there are currently no available techniques for detecting such debris in space.

One way of determining the flux of such articles, and getting some idea of their orbital properties, may be to detect them as they re-enter the Earth's atmosphere, forming artificial meteors. Radars operating in the HF-VHF bands have been used for many years to detect natural meteors, these being predominantly in the size range straddling 1 mm. Such meteor radars have been operated by the University of Adelaide for four decades. Building upon this expertise, a programme has begun to investigate the feasibility of detecting space debris in this way.

After this exploratory stage it is intended that the Jindalee over-the-horizon radar in central Australia be used; this is the most powerful detector of meteors ever operated, and initial studies show that it may be ideally suited for debris studies due to its antenna patterns.

4. International collaboration on space debris

Australia is represented on a Japanese committee on space debris. This group involves a variety of scientists and engineers from government organizations and industry, and is to consider a Japanese national response to the growing debris problem, particularly with respect to their involvement in the Space Station.

CHILE

[Original: Spanish]

The Committee for Space Affairs of Chile has examined fragments of space debris, presumably originating from the Soviet orbital station Salyut 7. The debris was discovered on 7 February 1991, in southern Chile, about 13 kilometres west of the city of Puerto Varas. Attached is a report prepared by the Committee for Space Affairs concerning the analysis of the remains of the orbital station Salyut 7.

Annex

REPORT ON SPACE DEBRIS FOUND IN SOUTHERN CHILE

(7 February 1991)

I. BACKGROUND

A. On 7 February 1991, at approximately 0200 hours local time, something resembling a shooting star was seen traversing the sky from west to east in the vicinity of Nueva Braunau, in the Tenth Region of the national territory. Subsequently, at approximately 1500 hours on 7 February, a local farmer found a cylindrical metal object, which was removed by carabineros from Puerto Varas and delivered to the Air Force for analysis and evaluation.

B. The Air Force, through its Third Air Brigade based in Puerto Montt, is recovering the remains of the debris and sending them to the Committee for Space Affairs.

II. DETAILS ON THE LOCATION AND IDENTIFICATION OF THE RECOVERED DEBRIS

A. Location

1. Location of the fallen debris. The space debris was seen by residents of the area on 7 February 1991 at approximately 0200 hours, traversing the sky from west to east and resembling a shooting star.

2. On 7 February 1991, on a farm in Nueva Braunau, at approximately 1500 hours, while baling fodder for livestock, farmers found an unfamiliar cylindrical metal object. The site of the discovery is approximately 13 kilometres west of Puerto Varas and 500 metres south of the road linking Nueva Braunau with Puerto Varas and perpendicular to the longitudinal southern highway (Route 55), with the coordinates 41°19' south, 73°05' west (see appendix). According to eyewitnesses (although neither they nor anyone else observed the impact), before impact the debris described a trajectory from west to east.

3. Identification of the site of the impact. The area of impact of the cylindrical artefact was a field used to produce fodder for livestock. At the site of the impact, the debris did not cause any apparent damage; no traces of the impact or fall of the artefact were detected, nor did it leave any visible marks.

B. Identification of the object

1. Preliminary technical inspection

Before the aforementioned object was taken to the laboratory, visual technical inspection tests were conducted in order to rule out possible radioactive contamination. The following tests were carried out:

(a) Measurement with a telescopic sensor using a 4 (M) Teledetector 61 12D. Results: 0.10 MR/h (background radiation level);

(b) Measurement with a Szintomat scintillation counter 6134. Results: 0.010 MR/h (background radiation level);

(c) Measurement with Berthold contamination detector. Results: negative (no contamination);

(d) The object was measured and weighed, with the following results: length of cylinder, 2.80 m; diameter, 0.46 m; thickness, 3 mils; weight, 6 kg;

(e) Detailed visual inspection revealed that the material (cylinder) had resisted considerable temperatures. Photographic set of different views of the object.

2. Laboratory

(a) Spectrometric analysis

As a result of a spectrometric test using Berpro and Radam analysers, the presence of radioactive elements in the object's original composition or of contamination resulting from its operation or trajectory was completely ruled out.

(b) X-ray fluorescence analysis

An X-ray fluorescence analysis yielded the following data on the composition of the object:

Titanium (Ti)	Normal to abundant concentration
Chromium (Cr)	Abundant concentration
Iron (Fe)	Abundant concentration
Nickel (Ni)	Normal to abundant concentration
Niobium (Nb)	Probable presence in small concentrations
Manganese (Mn)	Probable presence in small concentrations
Molybdenum (Mo)	Normal to abundant concentration

(c) Activation analysis

Laboratory analysis yielded the following data:

Major elements	Concentration (%)	Absolute standard deviation
Iron (Fe)	68.7	3.4
Chromium (Cr)	15.6	0.78
Nickel (Ni)	9.2	2.8
Manganese (Mn)	1.03	0.03

Minor elements	Concentration (Parts per million)	Absolute standard deviation
Cobalt (Co)	949	47
Molybdenum (Mo)	860	66
Tungsten (W)	508	25
Antimony (Sb)	44	10
Arsenic (As)	3.4	0.2
Zinc (Zn)	200	

Note: In this laboratory, because of the high concentration of chromium, it was not possible to determine the concentration of titanium.

3. Laboratory results indicate that the component materials are used in the aerospace industry and that the object found was a product of advanced technology, thereby confirming that it is a piece of space debris.

C. Other information

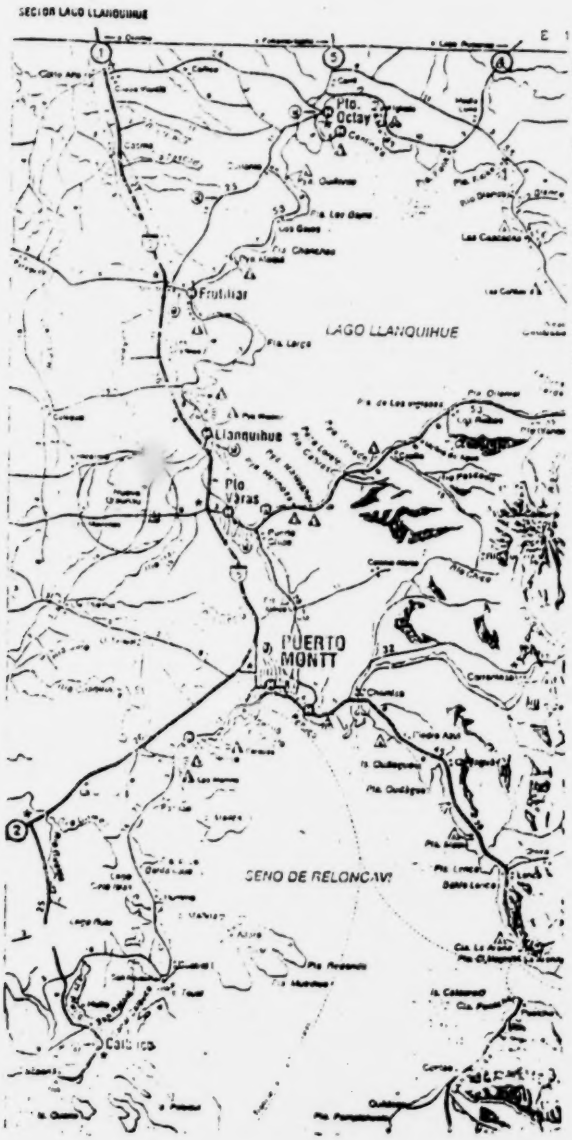
After nine years in orbit, the abandoned Soviet space station Salyut-7 re-entered the Earth's atmosphere on 6 October 1991 at 1044 hours Eastern Time.

That space vehicle was launched in 1982 and used by cosmonauts until 1986; it had a length of 90 feet and a weight of 43 tons; its orbital speed was 17,000 mi/hr.

Its re-entry into the atmosphere left a luminous trail in a north-easterly direction, crossing the skies of southern Chile and Argentina, where the object presumably fell.

Appendix

GEOGRAPHICAL INFORMATION REGARDING THE SITE OF DISCOVERY OF THE SPACE DEBRIS



CUBA

[Original: Spanish]

The Academy of Sciences of Cuba declares that Cuba is not engaged in space research and does not produce space debris.

FIJI

[Original: English]

The Government of the Republic of Fiji has not conducted national research on space debris.

JAPAN

[Original: English]

The following working papers on space debris were written by the specialists who play a major role in the scientific studies on this matter. The future policy of the Government of Japan will not be restricted by these papers.

The Government of Japan hopes that these working papers will contribute to further examination of this question.

Annex I

STUDY OF SPACE-BASED MEASUREMENT AND COLLISION PREDICTION

1. Introduction

Measurement of space debris is one of the most fundamental tasks in the space debris problems. This area seems to be one in which the National Space Development Agency (NASDA) can play an effective role towards better understanding and solution of the problem. Space-based measurement, i.e. measurement by a sensor on board a spacecraft, will help avoid collision of debris to the same spacecraft and also complement and extend ground-based debris data.

NASDA took up feasibility studies on orbit determination and collision warning by use of space-based measurement. Orbit determination improves debris data catalogues and also makes possible collision prediction, but collision prediction may not rely on orbit determination. In the present paper, discussion is limited to a method of collision warning that does not require orbit determination.

2. Collision prediction analysis

(1) Characteristics of relative velocity

Direction and magnitude of a debris object relative to a spacecraft was studied to define requirements of attitude and ranging of debris sensors. The study was performed under spacecraft conditions of altitude-500 km, assuming the Space Station. Range of debris orbits calculated is: eccentricity, 0-0.2, perigee altitude, 300-500 km and relative orbital inclination, 0-369 deg.

Figure 1 shows speed versus azimuth angle of debris at the instant of collision as seen from the spacecraft. It is seen that when the azimuth is over +/- 90 deg, i.e. debris is approaching from between the side and behind, relative speed is smaller than 3 km/s. For likely cases, which has azimuth within +/- 30 to 90 deg, collision velocity ranges from 2 to 14 km/s, and is 8 km/s in average.

Figure 2 shows elevation versus azimuth of debris at the instant of collision, as seen from the spacecraft. When the azimuth is within +/- 90 deg, the elevation falls within +/- 10 deg, which means very close to the local plane. If JEM is considered, the elevation extends over +/- 10 to 40 deg, since it is located at the rear of the Space Station. This must be taken into account in sensor requirements considerations.

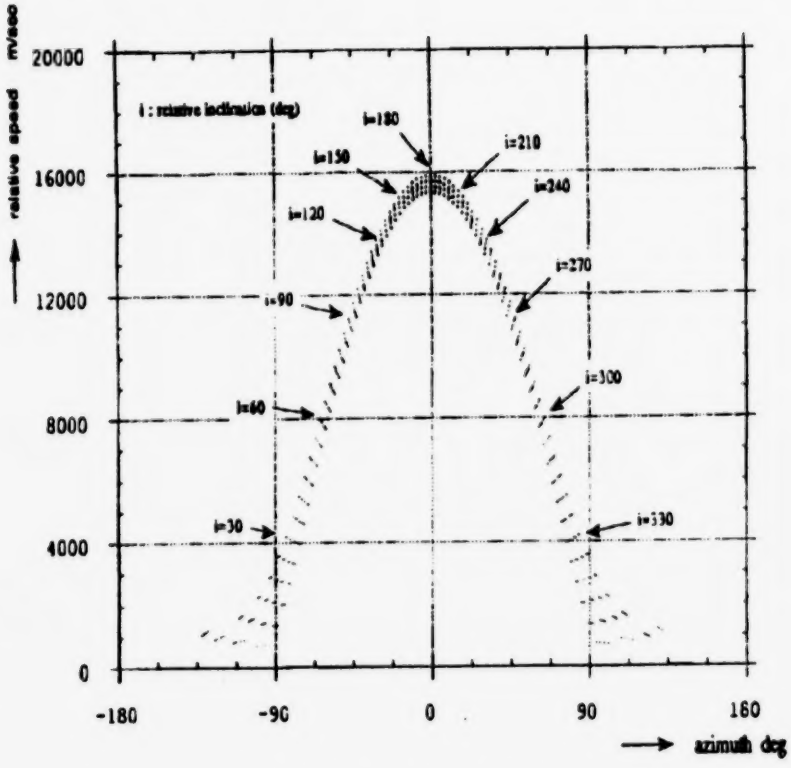


Fig. 1 Relative speed and direction of debris at collision

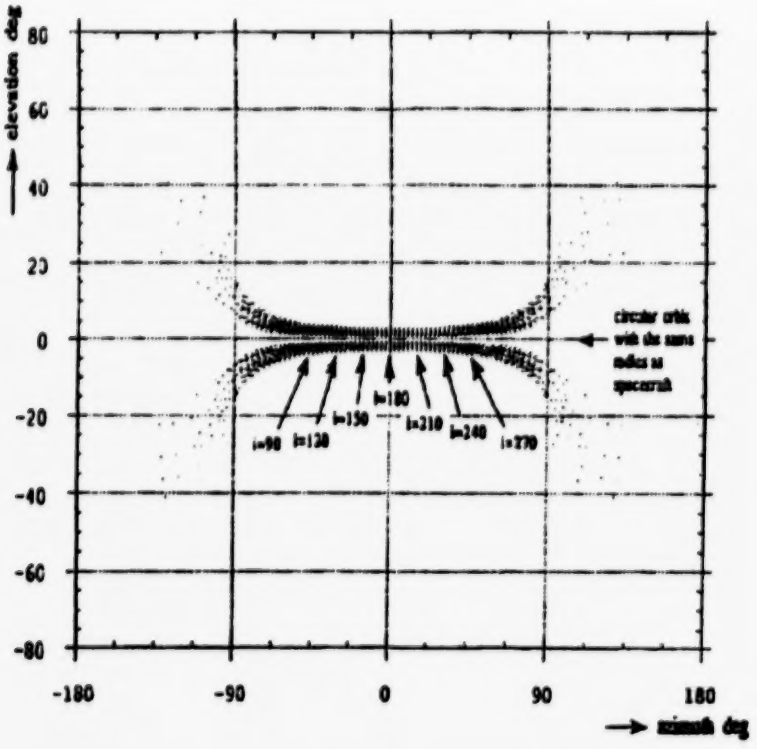


Fig. 2 Direction of debris at collision as seen from spacecraft

(2) Characteristics of debris trajectory

For the in situ (or immediate detection mode) collision prediction, it is necessary to observe debris trajectories from the spacecraft. Assuming the spacecraft to be that with 300 km altitude, trajectories were analysed for debris orbital elements extending sufficiently widely as follows:

a: semi-major axis: 6378+ (300-20500) km

e: eccentricity: 0 - about 0.75

i: relative inclination: 0 - 120 deg

Figure 3 shows a debris trajectory projected on the local plane of the spacecraft, with the point of collision at the point XL=0 and YL=0. Figure 4 shows the relation between azimuth and elevation angles and the range (distance) for the same object as in figure 3. Similarly, figure 5 and figure 6 show the trajectory and angles with regard to distance, respectively, for an object with another orbit. The first case represents a common LEO debris orbit, and the second can roughly represent the Molniya type orbit.

It may be seen from these results that the debris azimuth is either virtually constant, or its change rate is constant if there is any noticeable change, all the way from the detectable limit until collision.

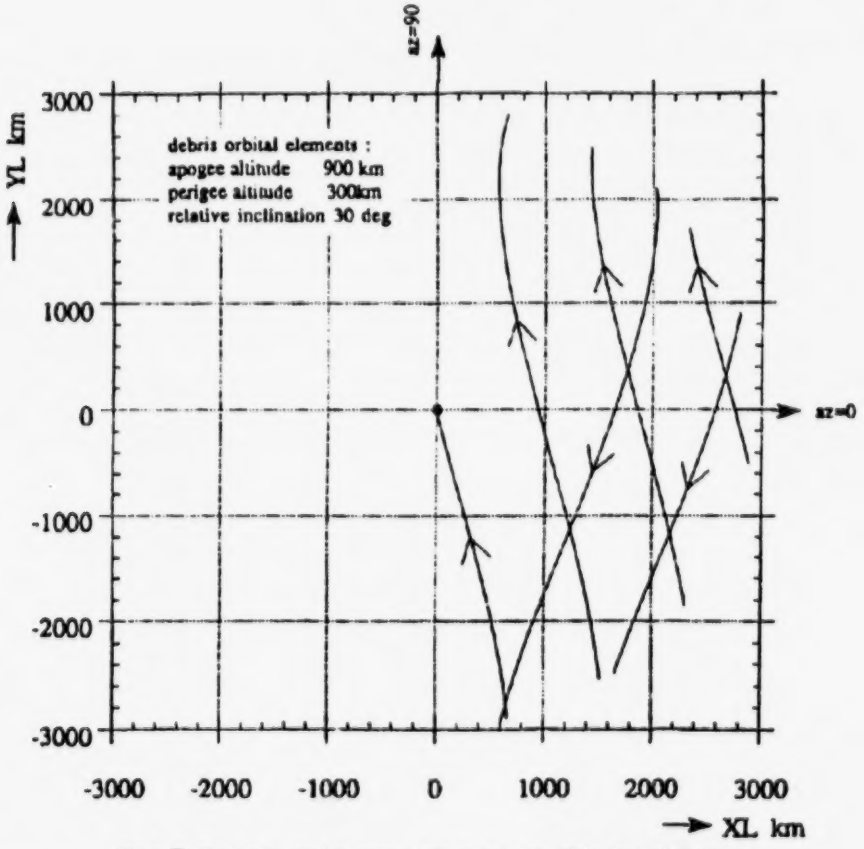


Fig.3 Debris trajectory on spacecraft's local plane

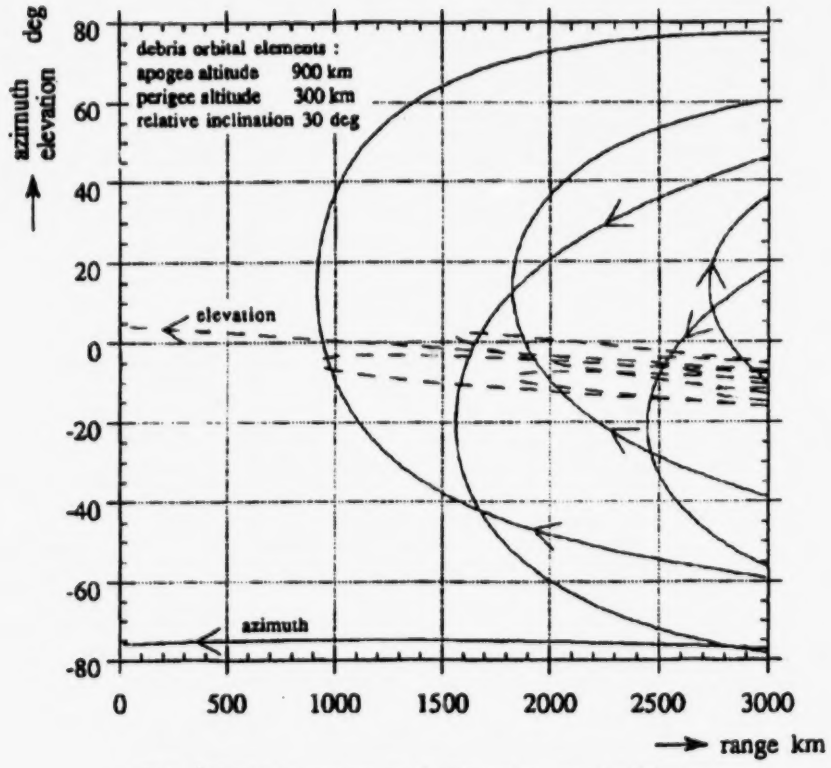


Fig.4 Debris range and direction angle history

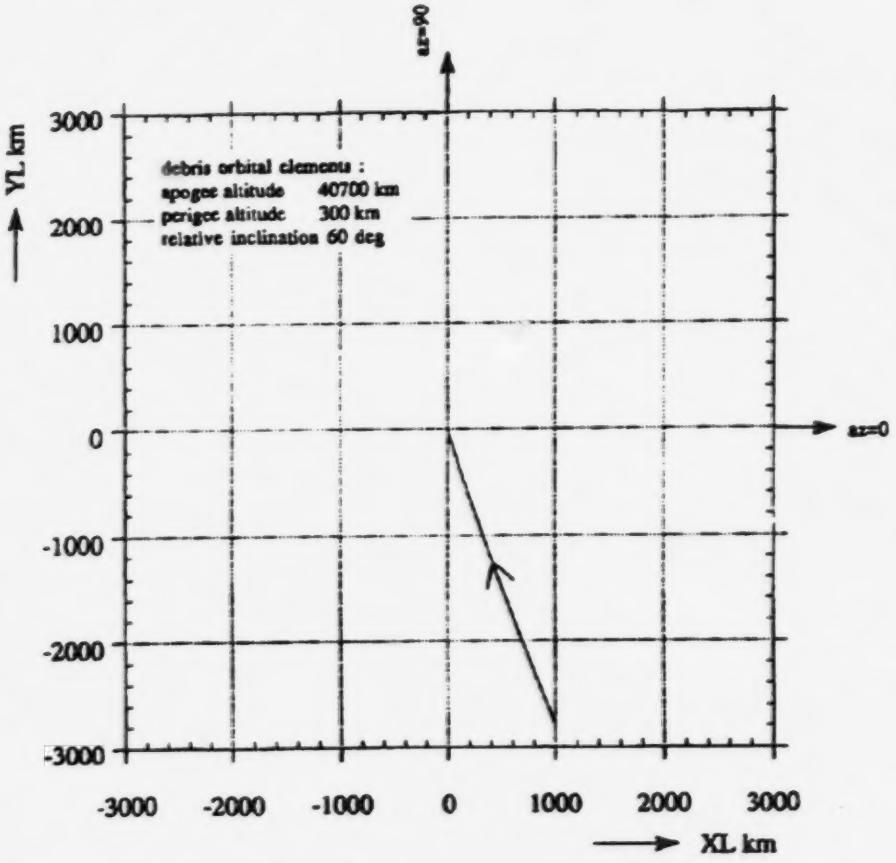


Fig.5 Debris trajectory on spacecraft's local plane

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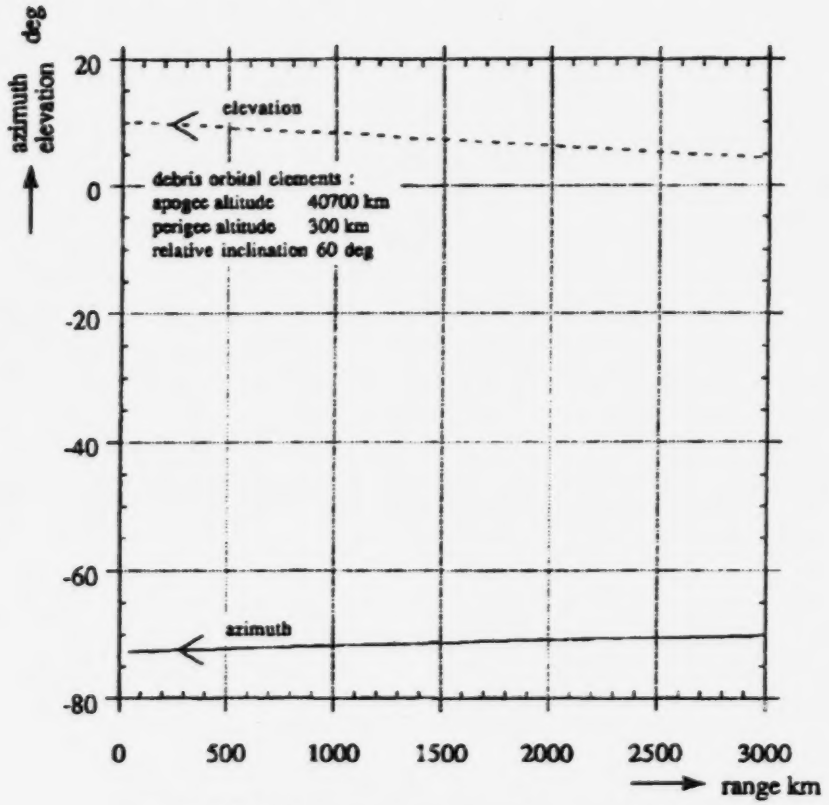


Fig.6 Debris range and direction angle history

3. Conclusions

1. LEO debris can be observed for a few times before collision.

2. Once an object is detected, collision warning is possible by only watching the change of its azimuth, and it is not necessary to fully determine its orbit.

3. Collision is to take place in a few minutes if the azimuth is virtually constant or changing at a constant rate.

NASDA will perform further studies to define collision warning/non-warning criteria that are valid for most possible cases.

Annex II

A BRIEF OVERVIEW OF SPACE DEBRIS STUDIES

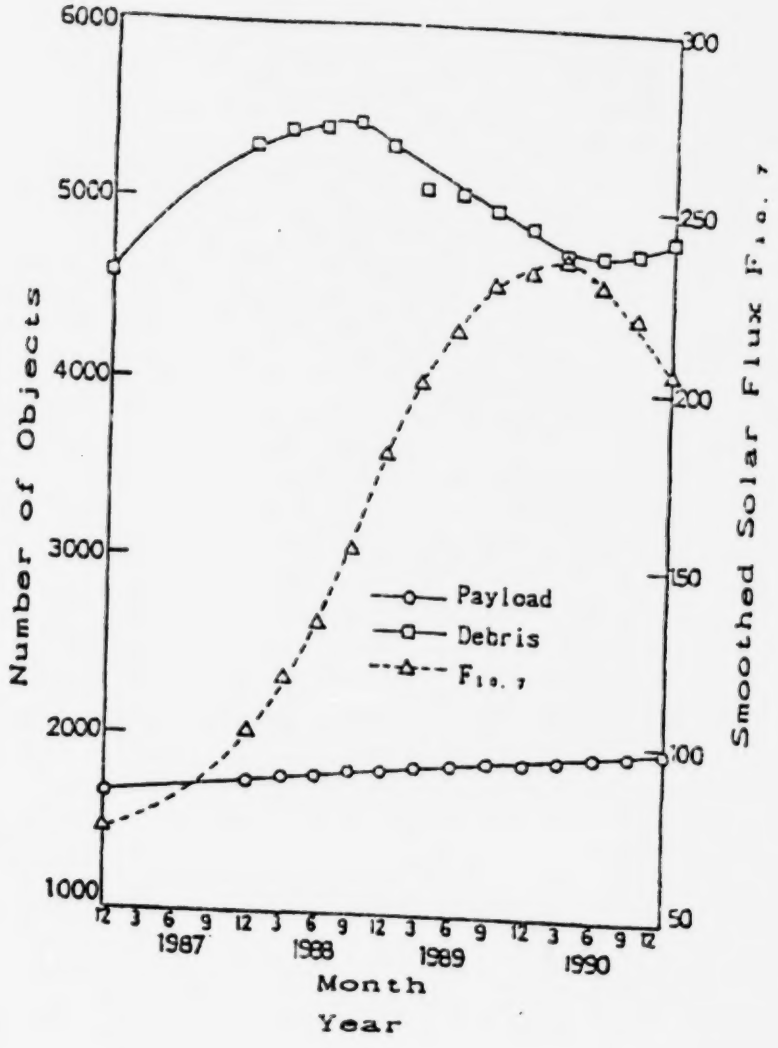
1. General survey and investigation of the space debris problem

As a design environment of large space structures, the space debris problem has been surveyed and studied in the field of observation, cause, modelling and protection.

1. The NASA Satellite Situation Report has been surveyed in order to understand the space debris environment. As an example, the trackable payloads and debris are plotted in figure 1 along with solar F10.7 radio flux. The payloads are seen to be increasing at a constant rate. On the other hand, the rate of growth of debris is seen to be decreasing with the increase of solar activity, because during solar maximum the atmosphere is heated and the atmospheric density at high altitudes increases. Thus debris population is noticeably affected by the 11-year solar cycle.

2. The modelling of collision and explosion phenomena has been investigated. The breakups of rocket upper stages and satellites are simulated by a fragmentation model in which a square plate is randomly sliced into N x N pieces. A log-normal distribution is proved applicable in case of explosion-induced fragmentation, as shown in figure 2.

3. In relation to the design of the Japanese Experimental Module (JEM), the research outputs obtained in the Apollo/Skylab era have been reappraised and various design formulas have been investigated with a combined effort with NASDA. One example is shown in figure 3, in which the effectiveness of aluminium shielding is experimentally studied. Optimum design procedures and fracture control studies are being planned by accumulating extensive experimental data.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Smoothed Solar Flux F10.7
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Month
Year

Fig.1

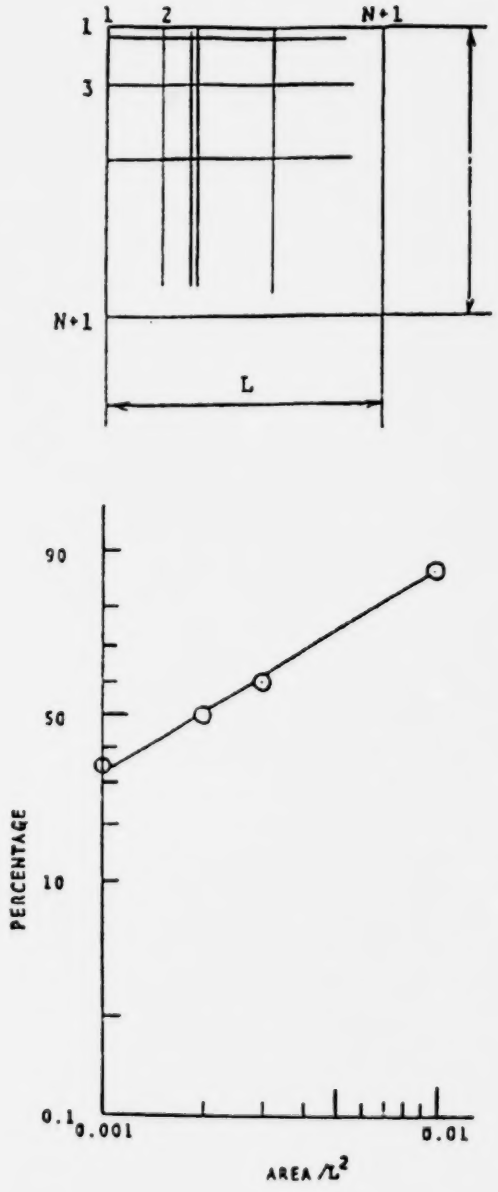
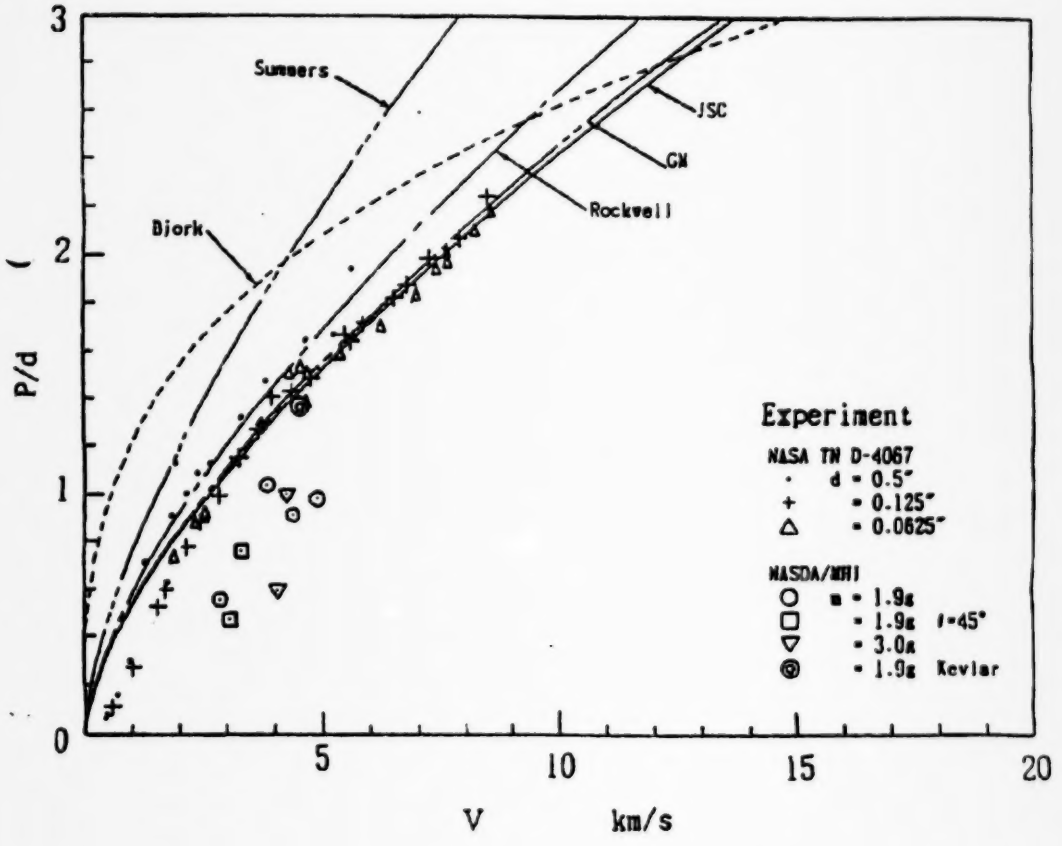


Fig.2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= 0.125"
= 0.0625"
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m = 1.9g
= 1.9g θ=45°
= 3.0g
= 1.9g Kevlar

Fig.3

/...

2. Study of hypervelocity impact phenomena and shielding designs

1. For the hypervelocity impact tests, specimens which consist of an aluminium alloy or a carbon fibre reinforced plastic (CFRP) shield and an Al alloy backup sheet are now being fabricated. The range of impact velocity is planned to be 2-7.5 km/sec.

2. The algorithms of hydrocodes are being investigated.

Annex III

OPTICAL OBSERVATION OF GEOSTATIONARY ORBITING OBJECTS USING A 1.5-METRE TELESCOPE SYSTEM WITH LOW-NOISE CCD CAMERA

1. Preface

A geostationary orbit is one of the most valuable orbits for satellite telecommunications and Earth observations. The probability of collision between satellites located in the same orbit or between geostationary orbiting debris and a satellite in a transfer orbit has been considered to be negligibly small. However, in the near future, the possibility will increase as the satellite population grows. Therefore, a technological development of monitoring geostationary orbiting objects is important.

An optical ground facility named Space Optical Communication Research Centre has been constructed in order to develop the future technologies for optical communications. This centre will be used as a fixed ground station for space optical communication experiments using a geostationary satellite (ETS-VI). The precise tracking of the geostationary satellite is one of the most important technologies to be performed in the space laser communication experiment. In this station, a 1.5-metre diameter Cassegrain type telescope is constructed to receive the laser beam from the ETS-VI. The station also has a low-noise CCD camera and an image data-processing computer. Major specifications of the telescope and performance of the CCD camera are shown in tables 1 and 2, respectively.

The present report shows some preliminary results of optical tracking of geostationary satellites by using the 1.5-m telescope with the CCD imaging system.

Table 1 Major Specifications of the Telescope

Main Telescope	
Primary Mirror Aperture:	1.5 m
Focal Length:	2.25 m
System Focal length:	infinity for Coude focus 18 m for other focuses
Mount and Control	
Structure:	Az/El Gimbal mount.
Az-El Perpendiculacy:	0.1 arc-sec.
Encoder Resolution:	0.0001 deg.
Tracking Velocity:	15 deg/sec(Az) 5 deg/sec(El)
Tracking Accuracy:	1 arc-sec.

Table 2 Performance of the CCD Camera

CCD (GEC Hirst Research Lab., England, P8600 device)		
Type:	Three Phase CCD, Frame Transfer	
Chip Size:	385x578 pixels(8.5x12.7mm)	
Pixel Size:	22x22 μm^2 each	
Performance		
Response Wavelength:	0.38~0.92 μm(λc=0.75 μm)	
Operational Temperature:	140 K	
Peak Quantum Efficiency:	0.6	
Readout Noise(r.m.s):	7.8 $\pm$0.6e	
Output Node Capacitance:	0.124 $\pm$0.011pF	
Dynamic Range:	3×10^5	
Filters	V band:	0.498 —0.591 μm
	R band:	0.630 ~0.762 μm
	I band:	0.820 ~1.15 μm
Field Of View	Nominal:	84'.7x97'.2
	Enlarged:	256"x384"

2. Results of satellite observation

The first tracking experiment for geostationary satellites began in 1989. CS-2a and CS-2b were tracked. Figure 1 shows the relative comparison between the tracking data shown by the open circle, and the calculated value from a NASDA orbital element, shown by the solid line with a time marker of 10 minutes each. The resultant tracking error was 0.001 degrees. Table 3 summarizes the results of the optical tracking experiment for several domestic geostationary satellites. The brightest of them was JCSAT-2. For the darker satellites, such as CS-3b, the S/N ratio could be improved by using the narrow band filter.

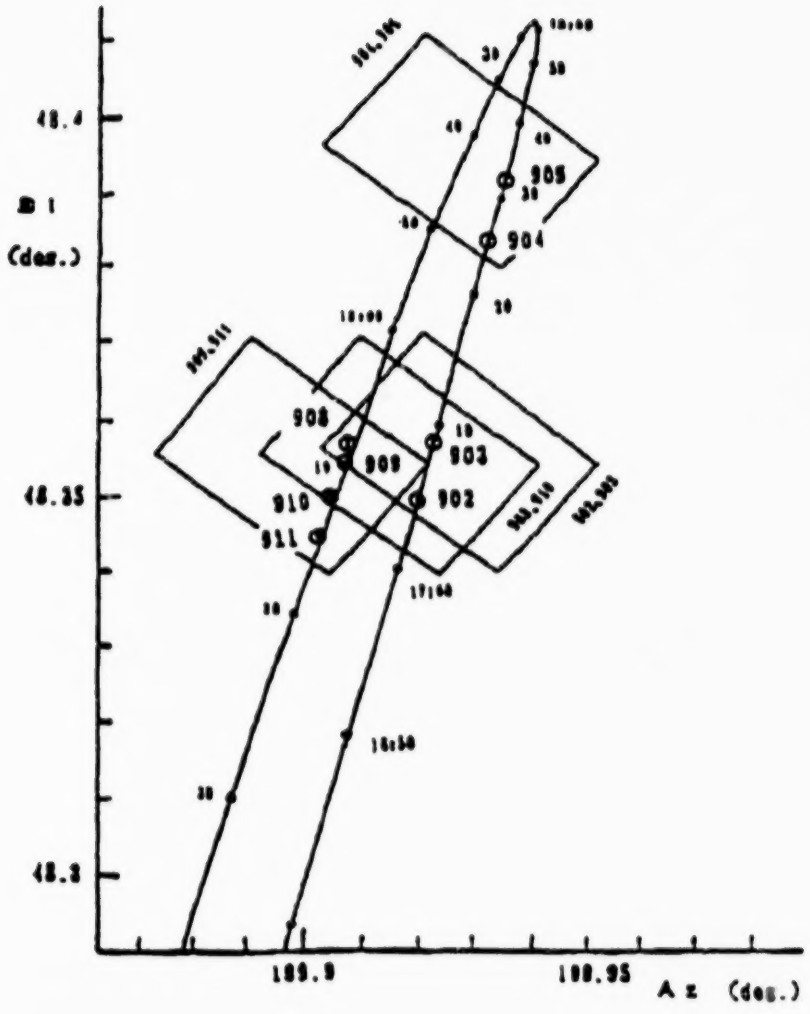

Figure 1 Relative Comparison between the Optical Tracking and Orbital Prediction

Table 3 Summary of the Geostationary Satellite Tracking

Sat. Name	Longitude deg.	Exposure sec.	Read-Out Count	Mag.
CS-2a		5	1.01×10^{5}	13.8
CS-2a		5	7.64×10^{4}	14.1
ETS-V	150.0	5	2.39×10^{5}	12.2
CS-3b	136.0	10	1.64×10^{5}	13.4
CS-3b	136.0	1	2.24×10^{4}	13.0
CS-3b	136.0	10	0.80×10^{5}	14.1
BS-2b	110.0	10	1.54×10^{6}	10.9
JCSAT-1	150.0	10	5.53×10^{6}	9.5
JCSAT-2	154.0	10	6.40×10^{6}	9.4
CS-3a	132 0	10	8.62×10^{5}	11.6
CS-3b	136.0	10	9.27×10^{5}	11.5
CS-3a	132.0	100*	5.00×10^{6}	12.2
CS-3b	136.0	100*	1.90×10^{6}	13.2
BS-2b	110.0	100*	2.01×10^{6}	13.1
JCSAT-2	154.0	100*	4.71×10^{6}	12.2
JCSAT-1	150.0	100*	4.26×10^{6}	12.3

3. Conclusion

It turned out to be quite easy to track geostationary satellites using the CCD imaging system whenever the sky was clear at night. The limiting magnitude of the telescope system was estimated to be about 19^m at a 10-second integration time by observing Japanese domestic geostationary satellites. The system will be effectively used to survey geostationary orbiting objects, such as operational/retired satellites and debris.

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NORWAY

[Original: English]

Norway has not done any research on space debris.

POLAND

[Original: English]

Research in Poland concerning space debris is of an exploratory character and is a part of broader investigations connected with the space environment and with maintaining outer space for common, peaceful uses.

One of the results of these studies was a working paper submitted by Poland to the thirty-fourth session of the Committee on the Peaceful Uses of Outer Space, held at Graz, Austria, in May-June 1991, proposing the elaboration of a report on the protection and preservation of the outer space environment, especially activities potentially affecting the Earth environment (A/AC.105/L.190).

SWEDEN

[Original: English]

Sweden does not carry out any national research on space debris. Through the Swedish National Space Board support is given to the activities in this field within the European Space Agency (ESA).

UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND

[Original: English]

SPACE DEBRIS STUDIES WITHIN THE UNITED KINGDOM

Overview

The deleterious space debris environment represents an immediate and increasing hazard to all space operations. The obvious hazard that space debris represents is the collision risk between operational vehicles and debris objects.

The only natural mechanism for the removal of space debris is orbital decay due to the influence of atmospheric drag. Unfortunately this only acts at altitudes up to 1,500 km. The rate of orbital decay increases with higher solar activity, which causes an expansion of the upper atmosphere and thus increased drag on space objects in low Earth orbits. Solar activity reached a

maximum in early 1991, which caused an increase in the re-entry of satellites and debris. However, we will have to wait until the next century for the next peak in activity and subsequent effective removal of debris objects. Active measures for debris control and removal must be sought in the meantime.

The uncontrolled re-entry of large space debris objects such as Salyut 7 and Skylab represents a hazard to the surface of the Earth. This is due to the large in-orbit mass of the vehicles and the small (10 per cent) but significant mass proportion that survives re-entry and impacts the ground. In addition to these highly publicized and infrequent events, the orbits of smaller catalogued objects decay on a daily basis. Further analysis of these frequent events may enable us to gain better insight into the mechanism of natural decay.

Mathematical modelling plays an important role in characterizing the debris environment and providing the link between the catalogued objects and the untrackable population. Traffic models derived from market analysis, break-up (explosion and collision) models derived from laboratory experiments and propagation models accounting for perturbative influences on the motion of the debris objects all help to characterize the current environment and allow prediction of its future evolution and the investigation of debris production and reduction phenomena. The meagre data currently available suggests that the small-particulate artificial population is concentrated in discrete regions in a similar manner to the large object population. This is a departure from the even distribution about near Earth space observed for the natural meteoroid environment and assumed for the debris population in current mathematical models. Such discrepancies may explain why there are many more encounters between space debris objects and operational vehicles than are predicted by the current models.

One of the major sources of debris is the fragmentation of vehicles due to the explosion of propulsion systems or batteries. The redesign of vehicles to enable safe venting of fuel and pressurants and the integration of protective circuits to prevent the explosion of batteries during short circuits should be encouraged. This practice should be mandatory for vehicles in high energy orbits such as the geostationary transfer orbit (GTO) which will continue to intersect LEO for hundreds of years.

In the case of launch vehicle upper stages, appropriate thrusting with a very small propellant budget can reduce the perigee height so that the orbit decays within the atmosphere soon after delivery of its payload. Phasing of the launch window with the lunisolar cycle permits the harnessing of their perturbative influence to reduce the perigee height and orbital lifetime and therefore decreasing the collision probability of the upper stage.

Specification of graveyard orbits (GYOs) above the geostationary ring and provision of adequate fuel budgets to enable boosting at end-of-life should be universally adopted. This will ensure that the Geosynchronous Earth Orbit (GEO), which has no natural mechanism for removing debris objects, will not become overcrowded and a critical spatial density of collision partners

reached. At the most heavily populated longitudes, co-location of satellites and therefore appropriately phased station keeping and operational strategies between agencies should be adopted. The definition of standard manoeuvres for trajectory control is envisaged.

Spacecraft system and subsystem design should evolve to provide adequate redundancy and to ensure that hypervelocity collisions with particulates does not result in failure of the total system and the rendering of the vehicle as an additional piece of debris.

Study programmes and capability within the United Kingdom

Space debris activities within the United Kingdom are focused through the British National Space Centre at the Royal Aerospace Establishment (RAE), DRA Farnborough. Since the beginning of the space age RAE has been compiling the RAE Table of Earth Satellites.[1] This is a catalogue of satellites and associated hardware that are launched into orbit about the Earth. Monthly updates provide information on launch date, orbital lifetime, shape, size and mass of objects and the associated orbital elements determined by US SpaceCom at a particular epoch. The table represents a valuable reference tool for the tracking community and has formed the basis of a number of satellite catalogue databases including the DISCOS[2] database initiated and maintained by the European Space Agency (ESA).

DRA also carries out a re-entry prediction service for risk objects such as the Salyut 7/Kosmos 1686 space station which impacted the surface of the Earth on 7 February 1991. The recent re-entry prediction campaign[3] provided information to both the European Space Agency (ESA)[4] and a number of European States. Research studies are continuing in an attempt to improve re-entry prediction models, but the greatest problems that are encountered are still found to be uncertainties in the behaviour of the atmosphere, lack of vehicle attitude, mass and aerodynamic information. A method[5] pioneered by RAE which does not require such information uses observations of the rate of contraction of the orbit to determine the time of re-entry. This technique does however rely upon frequently updated orbital elements and if, as was the experience with the Salyut 7/Kosmos 1686 re-entry prediction campaign, information is not distributed in a timely fashion to the user community (especially as the time of re-entry approaches) the uncertainty in the predicted re-entry date will remain of the order of 10 per cent of the remaining orbital lifetime.[6]

Debris mitigation strategies have also been explored. The probability of collision in space is dependent upon the number of objects in orbit, the collision cross-section (related to size) of objects, the closing velocity between objects and residence time in orbit of the objects. It is therefore apparent that the massive launch vehicle upper stages which are left in high-energy, highly eccentric orbits following deployment of geostationary satellites will represent a collision hazard to vehicles operating in low-Earth orbit (LEO) for many years following initial orbital injection. The

recent near misses between the STS-48 and STS-49 Space Shuttles and the Soviet launch vehicle upper stages highlight the growing problem. A recent study[7] by RAE explored the strategies available for removing a launch vehicle upper stage from initial injection into geostationary transfer orbit (GTO). Among the techniques considered, which included the use of ballutes (drag augmentation devices) and appropriate choice of launch window to harness lunisolar perturbations to orbit to decrease orbital lifetime, the active propulsive deorbiting of upper stages using either the main propulsive system or a dedicated unit appeared to offer the most effective and practical solution to the problem.

Complementary to these studies, DRA is also designing a particulate detection experiment[8] which will be mounted on a satellite STRV1[9] which it is planned to inject into GTO in late 1993. The detector will provide particulate environment information in a range of orbits from just below GEO down to LEO and will add to the still sparse database on the population derived from Long Duration Exposure Facility (LDEF) studies. Using orbital theory developed at RAE, it is hoped that it will be possible to derive information on the population of 1 mm to 10 cm fragments from observation of the spatio-temporal behaviour of the much smaller particulate population that will be sensed by the detector.[10]

Future studies will seek to construct time-variant models of the population to enable accurate collision probabilities to be calculated for operational vechicles and to determine the effectiveness and impact on the environment of different debris mitigation strategies. LEO constellations will receive attention under this progrmme.

In its role as technical adviser to the United Kingdom Ministry of Defence, DRA defines the altitude of graveyard orbits into which Skynet and North Atlantic Treaty Organization (NATO) satellites will be boosted at the end of their operational life on the geostationary ring. This altitude is currently 500 km above the geostationary ring, in line with ESA policy.

Another United Kingdom centre of research into space debris is the Unit for Space Sciences (UNISPACE) at the University of Kent, Canterbury. The history of measurements of hypervelocity impacts in space began in the early 1960s with the United Kingdom Skylark and Ariel rockets.

UNISPACE experiments have flown on a wide range of United Kingdom and United States rocket and satellite missions measuring the space environment using recoverable techniques (Space Shuttle, LDEF and ESA-Eureca) and in situ electronic detection (Ariel II, Ulysses, Galileo and the Cassini missions). These measurements define the size distribution of particulates, the angular distribution as perceived from a deployed satellite, and using algorithms developed for LDEF, modelling transformations to yield particulate orbital distribution parameters in the geocentric reference frame.

The need to interpret measurements and to develop detection techniques has led UNISPACE to develop an expertise in hypervelocity impact penetration

parameters. The development of a penetration relationship to 16 km/s based on experimental data acquired on a 2MV accelerator exemplifies an achievement in this area (the "Carey McDonnell and Dixon" formula) which relates to supramarginal impacts of micron dimension foils. Also studied (using the 2MV Van der Graaff accelerator) is the time-resolved ionization yield of hypervelocity impact processes and momentum exchange enhancement.

The resident impact facility suite at UNISPACE consists of a 2MV Van der Graaff accelerator capable of providing impacts of up to 90 km/s for micron and sub-micron dimension particulates. This is complemented by a two-stage light gas-gun which provides impacts of larger projectiles to 5 km/s.

UNISPACE has developed the DISCOS database for ESA. This provides real-time interactive facilities to study the characteristics of the currently known orbital population of catalogued objects. UNISPACE is currently involved with SIRA of Kent, United Kingdom, and the Royal Greenwich Observatory, United Kingdom, to study the techniques available to evaluate the space debris environment using ground-based and satellite-based optical techniques.[11] This research is also sponsored by ESA.

Appraisal

The debris population being generated by the current space-faring nations in near-Earth space represents an ominous legacy for the future. The proposed debris mitigation measures for the space environment do not seek to limit in-orbit operations; their purpose is to ensure that space-flight activities will be able to continue unrestricted for future generations. The debris problem can only be resolved by a coordinated effort on the part of the global scientific, technical and legislative community. The United Nations Scientific and Technical Subcommittee would seem the obvious focus for such a programme.

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DRA (Aerospace Division)
Royal Aerospace Establishment
Farnborough, Hants, England

RAE TABLE OF EARTH SATELLITES
(Year of launch 1991 continued)

8 May 1991
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	Name		Launch date, lifetime and descent date	Shape and mass (kg)	Size (m)	Date of orbital determination	Orbital inclination (deg)	Nodal period (min)	Semi major axis (km)	Perigee height (km)	Apogee height (km)	Orbital eccentricity	Argument of perigee (deg)
T L	Cosmos 2139*	1991-25A	1991 Apr 4.45 1 million years	Cylinder + panels + boom 1400	-	1991 Apr 13.8 1991 Apr 21.2	64.81 64.81	667.48 675.74	25300 25508	18698 19111	19145 19149	0.009 0.001	264 232
T L	Cosmos 2140*	1991-25B	1991 Apr 4.45 1 million years	Cylinder + panels + boom 1400	-	1991 Apr 12.4 1991 Apr 20.4	64.81 64.81	674.45 675.74	25476 25508	19039 19105	19156 19154	0.002 0.001	251 247
T L	Cosmos 2141*	1991-25C	1991 Apr 4.45 1 million years	Cylinder + panels + boom 1400	-	1991 Apr 13.8 1991 Apr 28.9	64.82 64.80	684.17 675.73	25720 25508	19147 19108	19536 19151	0.008 0.001	90 316
D	Cosmos 2139 third stage	1991-25D	1991 Apr 4.45 <1 day 1991 Apr 4	Cylinder	6.5 long? 4 dia	1991 Apr 4.5	64.80	87.51	6529	138	164	0.002	316
	Cosmos 2139 fourth stage	1991-25F	1991 Apr 4.45 1 million years	Cylinder 17300 full	5.5 long 4.0 dia	1991 Apr 5.8	64.79	675.53	25503	19109	19140	0.001	312
	Fragments	1991-25E,G											
T?	Anik E2** (Ariane 4-15)	1991-26A	1991 Apr 4.98 >million years	Box + panels 1803	3 x 2.8 x 2.3 23.7 span	1991 Apr 6.6 1991 Apr 10.1 1991 Apr 17.7	0.69 0.25 0.06	917.95 1195.40 1432.76	31291 37313 42101	14078 26119 35692	35748 35751 35754	0.346 0.129 0.001	187 180 116
	Ariane 4-15 third stage	1991-26B	1991 Apr 4.98 500 years	Cylinder 11760 full 1270 empty	9.9 long 2.6 dia	1991 Apr 5.6	4.27	636.71	24532	432	35876	0.722	181

* Glonass payload
** First 5th generation communications satellite for Telesat Canada.

UNITED
NATIONS

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COMMITTEE ON THE PEACEFUL USES
OF OUTER SPACE

NATIONAL RESEARCH ON THE QUESTION OF SPACE DEBRIS

Note by the Secretariat

Addendum

The present document contains information provided in replies received from Member States up to 20 February 1992.

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BULGARIA

[Original: English]

INVESTIGATION OF AIR AND SPACE SYSTEM SAFETY BASED ON ANALYTICAL CRITERIA

(Research paper by B. I. Madjarov, Space Research Institute)

The high reliability of aerospace systems ensures a very low risk of accidents arising from emergency situations (1:1,000,000 to 1:10,000,000) and a practically negligible risk of fatal accidents (1:10,000,000 to 1:1,000,000,000). The general approach to system standardization, both theoretical and practical, based on various methods of statistical investigation of phenomena, is unsatisfactory for the analysis of such situations and does not allow for realistic prediction of dangerous but low-probability phenomena.

We therefore suggest an approach and methods for the analytical evaluation of risks in high-reliability systems, such as space and aviation systems, nuclear power stations, etc. A principal consideration in relating the probability of specific situations to the risk of their leading to a serious accident is the investigation of the final terms of a statistical sampling procedure based on values characterizing the state of the systems in the form of a multi-modal distribution. This investigation is based on proof that the final terms are not determined by the distribution laws for the values that define the state.

Analytical criteria are suggested for estimating the risk level and determining its dependence on four groups of adverse factors: operator errors (in the operator-machine system and in polyergatic systems); technical systems failure (for different schemes of redundancy distribution); the effect of external adverse factors; and errors in the organization, planning, management and control of system performance.

Two basically different types of research are identified:

- Analysis of the functional failure of a system with identification of the type of failure; estimation of the probability of occurrence; verification of the range of all failure states and combinations of states without estimation of the consequences of their occurrence;

- Identification of specific situations arising from functional failures; determination of the conditional probabilities for preventing the failures under different stages and conditions; development of steps for lowering the risk level.

On the basis of this research, automated systems for real-time monitoring and control of safety levels may be developed, together with a combination of approaches for the statistical and analytical determination of risk criteria for different adverse factors.

CHINA

[Original: Chinese]

THE STATUS OF SPACE DEBRIS STUDIES IN CHINA

Submitted by the Space Debris Study Group

(March 1991)

INTRODUCTION

With the expansion of human activities in space and the steady increase in space debris (or space trash) resulting therefrom, the space environment is constantly deteriorating. If left uncontrolled, this situation will gravely endanger future space activities, presenting ever greater hazards, particularly to manned space flights of extended duration.

The problem of the pollution of the space environment caused by space debris has become a growing concern within international astronautical circles and the international community as a whole. The General Assembly, in its resolution 44/46, adopted in 1989, requested that States attach great importance to the problem of space debris and carry out research at the national level. In its resolution entitled "International cooperation in the peaceful uses of outer space", adopted on 11 December 1990, at its forty-fifth session, the General Assembly once again pointed out that, "considering that space debris is an issue of concern to all nations, ... it is essential that Member States pay more attention to the problem of collisions with space debris and other aspects of space debris, and calls for the continuation of national research on this question". In a letter addressed to Governments on 30 June 1989, the Secretary-General of the United Nations stated that the management of the space environment was a matter for international cooperation and urged States to conduct national research and submit studies thereon.

Outer space is an invaluable natural resource which is shared by all mankind. It is a common desire among States to control and reduce space debris and protect the outer space environment. This is a matter of profound concern to the Chinese Government.

In June 1989 the Ministry of Aviation and Astronautics began organizing a Space Debris Study Group in order to give impetus to research on the problem of space debris. On 28 December 1989, the Ministry of Aviation and Astronautics organized a seminar on space debris in Beijing for the first time. Specialists from the State Science and Technology Commission, the Commission of Science and Technology for National Defense, the Ministry of Foreign Affairs, the Chinese Academy of Science and the Ministry of Aviation and Astronautics took part in the seminar and exchanged information on their research on space debris. Three other seminars were organized in Beijing in August and December 1990 and March 1991, which dealt in depth with the current

situation and trends in the development of debris in outer space, space debris produced by Chinese space activities and the technological means of reducing the generation of space debris, and made recommendations concerning positions and policies to be adopted on the problem of space debris.

I. CHINESE SPACE OBJECTS IN ORBIT AND POSSIBLE SPACE DEBRIS RESULTING FROM THEM

From 1970 to 1990, China successfully carried out 28 space launchings, placing 32 artificial satellites of various types into low-earth, sun-synchronous and geostationary orbits (including the Asia-1 communications satellite and the first experimental satellite for Pakistan, both launched in 1990).

By the end of 1990, a total of 30 artificial satellites designed and produced by China had been launched into outer space (see table 1), of which 10 remain in orbit. Five of them are in geostationary orbits, and the remaining five in other orbits. A total of 20 satellites have either been recovered (12) or fallen to earth (8). For example, the Shijian-1 scientific experimental satellite (International Code No. 1971-18A), which was launched on 3 March 1971, remained in normal space operation for eight years until it fell on 11 June 1979. In another case, the Shijian-2 scientific experimental satellite (universal designation PRC-09) was launched into orbit on 20 September 1981, but based on telemetric data received at 0300 hours on 3 October 1981, an increase was detected in the satellite's rotational speed, from 15-20 rpm to nearly 162 rpm; at 1400 hours on the same day it disappeared and no further signals were received. From this it was concluded that the satellite had disintegrated as a result of its high speed of rotation. At that time, 10 pieces of debris were entered in the NASA Tracking Register, all of which have since fallen to earth.

By the end of 1990, China had launched into orbit the final stages of 28 launch rockets (see table 2), of which 19 have fallen to earth and 9 remain in low-earth or geosynchronous transfer orbits.

Statistics show that, by the end of June 1990, a total of 4,048 spacecraft had been launched in the world, with China accounting for about 0.7 per cent of all launchings. Based on information provided by the United Nations Committee on the Peaceful Uses of Outer Space, the space debris produced by States that are less active in space, including China, accounts for less than 0.3 per cent of all tracked objects world wide, and its effect on the outer space environment as a whole is minimal - insignificant when compared to that produced by major Powers active in space, such as the United States of America and the Soviet Union.

II. POSITIONS OF PRINCIPLE ON SPACE DEBRIS

1. Outer space is an area for joint exploitation by mankind as a whole, and the preservation of the space environment is a common obligation of all States.

2. States which are major producers of space debris have the major responsibility for preserving the space environment and controlling space debris.

3. Space debris is a global problem, and only through international cooperation can space debris be successfully controlled. In order to reduce and control the generation of space debris, international cooperation in and exchanges of space technology should be encouraged and promoted, and States with experience in space-debris control technology should provide free technical assistance to other interested States.

4. China, being a developing country, has conducted only a limited number of space launchings, which have produced an insignificant amount of space debris. However, to facilitate man's free exploration and exploitation of outer space, China will strengthen its cooperation with other countries and international organizations, including the United States of America, the Soviet Union, the European Space Agency (ESA) and Japan, in order to promote actively the exchange of information and technology, search together for effective ways to reduce the generation of space debris and make genuine efforts to preserve the space environment.

5. Research on technology for reducing space debris should be encouraged and strengthened and technical measures should be taken to deal with satellites and the final stages of rockets sent into medium and high orbits which are liable to explode, thereby controlling and reducing the generation of space debris in so far as possible.

6. A "space environment protection fund" should be established under the Committee on the Peaceful Uses of Outer Space. Such a fund would be used mainly to:

(a) Support international research and technological exchange on controlling the generation of space debris, especially research conducted by developing countries;

(b) Establish a registration, management and information exchange system for space objects of all States; and

(c) Support international legislation on the problem of space debris.

III. STUDIES ON TECHNOLOGICAL MEANS FOR THE REDUCTION OF SPACE DEBRIS

1. Measures taken by China to reduce space debris

Bearing in mind the need to minimize the number of abandoned objects left in space orbit and to prevent them from disintegrating in space, China has taken a number of measures with regard to certain rockets and spacecraft in the development of its space technology. For example:

(a) When the cap for the infra-red probe on the Fengyun-1 meteorological satellite was jettisoned, it remained tethered to the satellite;

(b) Launch rocket design departments have imposed stringent technical requirements with regard to enclosure in the design of satellite-rocket separation devices to ensure that separated items do not scatter outside the main structure;

(c) Technical improvements have been made in certain orbital designs for the launching of geostationary satellites, lowering the geosynchronous transfer orbit's perigee from 400 km to 200 km; this greatly shortens the orbital lifetime of rocket final stages, thereby contributing to the reduction of space debris.

2. Further studies on technological means

(a) To the extent that overall performance requirements permit, spacecraft design is improved by making use of tethering to reduce the number of objects separated from the spacecraft during the process of launching into orbit;

(b) When conditions permit, the following technological measures are taken to shorten the orbital lifetime of the launch rocket's final stage after satellite-rocket separation:

- In choosing from alternative orbital designs, preference is given to those with lower perigees;

- "De-orbiting technology" is employed. After a medium or high-orbit satellite has been launched into orbit, the altitude of the final-stage rocket is adjusted to send it into a lower orbit, causing it eventually to burn up in the dense atmosphere;

(c) For those final stages of launch rockets using self-combustible propellants, methods are devised to release promptly all residual propellants and high-pressure gases remaining in the final-stage rockets to prevent any explosion while they remain in orbit.

IV. LEGAL QUESTIONS RELATING TO SPACE DEBRIS

1. China acceded to the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (Outer Space Treaty) in December 1983 and to the Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space (Agreement on Assistance), the Convention on Registration of Objects Launched into Outer Space (Registration Convention) and the Convention on International Liability for Damage Caused by Space Objects (Liability Convention) in December 1988.

China signed both conventions relating to radioactive space debris, i.e. the Convention on Early Notification of a Nuclear Accident and the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency, on 26 September 1986 and deposited the instruments of ratification on 14 September 1987.

Furthermore, the Chinese Government attaches great importance to the draft principles relevant to the use of nuclear power sources in outer space that are being elaborated by COPUOS and its Legal Subcommittee, in particular those relating to the question of pollution caused by radioactive space debris. It has been active in promoting progress in this work.

The Chinese Government strictly fulfils its international obligations under the international treaties it has signed.

2. Whether the Liability Convention applies to damage done to a State's space object by space debris is currently a subject of international debate. One view holds that a State whose space debris causes damage to a space object of another State should be liable to pay compensation in accordance with the provisions of the Liability Convention, on the grounds that the Registration Convention states that a "space object" includes component parts of a space object as well as its launch vehicle and parts thereof. In reality, this is a very complex problem. Firstly, the Liability Convention stipulates that such liability should be based on fault; secondly, it is sometimes impossible to identify space debris and to determine to whom it belongs, so that neither the cause of the damage nor the party liable for it can be determined under the Liability Convention. However there is no legal basis for an arbitrarily extended interpretation of the Liability Convention.

3. As to whether the launching State's consent is required before space debris belonging to that State (including satellites no longer in use) is destroyed or removed, the Outer Space Treaty provides that the launching State on whose registry a space object is carried shall retain jurisdiction and control over such object. It also stipulates that States should conduct their activities in outer space with due regard to the corresponding interests of other parties. This provision is the basis for the view that, once space debris and abandoned space objects exert an adverse effect on the space activities of other States, the affected State may legitimately take appropriate measures (such as destruction or removal) to prevent damage. This

view is also subject to debate. In general, any State wishing to destroy, remove or take any other measures against another State's space debris, especially a satellite that is no longer in use, should seek the consent of the space object's registering State, without which it should not take action. Of course, whether debris resulting from confirmed disintegration or broken residual fragments should be excluded from this provision is open to discussion.

In view of the inadequacy of the provisions concerning space debris in existing treaties, agreements or customary law, new international agreements must be adopted on the basis of in-depth studies and thorough consultations in order to settle certain questions relating to space debris.

TABLE I

LIST OF CHINESE SATELLITES LAUNCHED INTO OUTER SPACE

Sequence No.	Date launched	International Code No.	Satellite name	Satellite mass (kg)	Initial orbit				Remarks
					Altitude of perigee (km)	Altitude of apogee (km)	Orbital inclination (deg)	Orbital period (min)	
1	24/4/70	1970-34A	Dongfanghong-1 satellite	173	439	2 384	68.5	114	
2	3/3/71	1971-18A	Shijian-1 satellite	221	266	1 826	69.9	106	Fallen to earth (11/6/79)
3	26/7/75	1975-70A	Technical experimental satellite	1 109	186	464	69	91	Fallen to earth
4	26/11/75	1975-111A	Re-entry-type remote sensing satellite	1 790	173	483	63	91	Re-entry module retrieved, remainder fallen to earth
5	16/12/75	1975-119A	Technical experimental satellite	1 108	184	187	69	90	Fallen to earth
6	10/8/76	1976-87A	Technical experimental satellite	1 082	191	2 145	69	108.8	Fallen to earth
7	7/12/76	1976-117A	Re-entry-type remote sensing satellite	1 812	167	489	59	91	Re-entry module retrieved, remainder fallen to earth
8	26/1/78	1978-11A	Re-entry-type remote sensing satellite	1 810	163	488	57	91	Re-entry module retrieved, remainder fallen to earth
9	20/9/81	1981-93B	Shijian-2 satellite	257	237	1 622	60	103	Fell to earth after disintegration
10	20/9/81	1981-93C	Shijian-2A satellite	483	237	1 622	60	103	Fallen to earth
11	20/9/81	1981-93A	Shijian-2B satellite	15	237	1 622	60	103	Fallen to earth
12	9/9/82	1982-90A	Re-entry-type remote sensing satellite	1 783	169	195	63	90	Re-entry module retrieved, remainder fallen to earth
13	19/8/83	1983-86A	Re-entry-type remote sensing satellite	1 842	175	404	63	90	Re-entry module retrieved, remainder fallen to earth
14	29/1/84	1984-8A	Experimental satellite	433	360	6 480	36	161	
15	8/4/84	1984-35A	Experimental communications satellite	433	35 598.9	35 792.8	0.62	1 431.5	Fixed at 125° E; has drifted away
16	12/9/84	1984-98A	Re-entry-type remote sensing satellite	1 809	174	408	68	90	Re-entry module retrieved, remainder fallen to earth
17	21/10/85	1985-96A	Re-entry-type remote sensing satellite	1 820	173	402	63	90	Re-entry module retrieved, remainder fallen to earth
18	1/2/86	1986-10A	Operational communications and broadcasting satellite	433	35 783	35 792	0.09	1 436	Fixed at 103° E, has drifted away

TABLE 1 (continued)

Sequence No.	Date launched	International Code No.	Satellite name	Satellite mass (kg)	Initial orbit: Altitude of periqee (km)	Initial orbit: Altitude of apogee (km)	Initial orbit: Orbital inclination (deg)	Initial orbit: Orbital period (min)	Remarks
19	6/10/86	1986-76A	Re-entry-type remote sensing satellite	1 820	175	397	57	90	Re-entry module retrieved, remainder fallen to earth
20	5/8/87	1987-67A	Re-entry-type remote sensing satellite	1 820	175	489	63	90	Re-entry module retrieved, remainder fallen to earth
21	9/9/87	1987-75A	Re-entry-type remote sensing satellite	2 100	205	315	63	89	Re-entry module retrieved, remainder fallen to earth
22	7/3/88	1988-14A	Operational communications satellite	441	35 786.4	35 862.6	0.07	1 438	Fixed at 87.5° E
23	5/8/88	1988-67A	Re-entry-type remote sensing satellite	2 100	175	400	63	90	Re-entry module retrieved, remainder fallen to earth
24	7/9/88	1988-80A	Fengyun-1 satellite	780	883	918	99.1	102.8	
25	22/12/88	1988-111A	Operational communications satellite	441	35 782.5	35 790.2	0.56	1 .1	Fixed at 110.5° E
26	4/2/90	1990-11A	Operational communications satellite	441	35 783.3	35 797.8	0.11	1 436.3	Fixed at 98° E
27	3/9/90	1990-81A	Fengyun-1 satellite	841	.6	905.7	99.9	102.9	
28	3/9/90	1990-81B	Daqi-1A satellite	3	900.6	905.7	99.9	102.8	Fell to earth on 12/3/91
29	3/9/90	1990-81C	Daqi-1B satellite	4	900.6	905.7	99.9	102.8	
30	5/10/90	1990-89A	Re-entry-type remote sensing satellite	2 100	210	328	63	89	Re-entry module retrieved, remainder fallen to earth

TABLE 2

LIST OF LAUNCH ROCKET FINAL STAGES PUT INTO ORBIT AT VARIOUS TIMES DURING CHINA'S LAUNCHING ACTIVITIES

Sequence No.	Date launched	Launch rocket	Payload	Payload mass (kg)	Altitude of perigee (km)	Altitude of apogee (km)	Orbital inclination (deg)	Orbital period (min)	Remarks
1	24/4/70	CZ-1	Dongfanghong-1 satellite	173	439	2 384	68.5	114	
2	3/3/71	CZ-1	Shijian-1 satellite	221	266	1 826	69.9	106	Fallen to earth
3	26/7/75	FB-1	Technical experimental satellite	1 109	185.8	464.1	69.01	90.9	Fallen to earth
4	26/11/75	CZ-2	Re-entry-type remote sensing satellite	1 790	173	483	63	91	Fallen to earth
5	16/12/75	FB-1	Technical experimental satellite	1 108	183.6	387	69	90.2	Fallen to earth
6	30/8/76	FB-1	Technical experimental satellite	1 082	191.2	2144.373	69.2	108.7	Fallen to earth
7	7/12/76	CZ-2	Re-entry-type remote sensing satellite	1 812	167	489	59	91	Fallen to earth
8	26/1/78	CZ-2	Re-entry-type remote sensing satellite	1 810	163	488	57	91	Fallen to earth
9	20/9/81	FB-1 (III)	Shijian-2 (3 satellites)	755	237.2	1 621.3	59.4	103.5	Fallen to earth
10	9/9/82	CZ-2C	Re-entry-type remote sensing satellite	1 783	169	395	63	90	Fallen to earth
11	19/8/83	CZ-2C	Re-entry-type remote sensing satellite	1 842	175	404	63	90	Fallen to earth
12	29/1/84	CZ-3	Experimental satellite	932	400	450	31.1	93	Fallen to earth

/...

TABLE 2 (continued)

Sequence No.	Date launched	Launch rocket	Payload	Payload mass (kg)	Altitude of perigee (km)	Altitude of apogee (km)	Orbital inclination (deg)	Orbital period (min)	Remarks
13	8/4/84	CZ-3	Experimental communications satellite	932	400	35 957	31.1	638	
14	12/9/84	CZ-2C	Re-entry-type remote sensing satellite	1 809	174	408	68	90	Fallen to earth
15	21/10/85	CZ-2C	Re-entry-type remote sensing satellite	1 820	173	402	63	90	Fallen to earth
16	1/2/86	CZ-3	Operational communications and broadcasting satellite	938	400	35 957	31.1	638	
17	6/10/86	CZ-2C	Re-entry-type remote sensing satellite	1 820	175	397	57	90	Fallen to earth
18	5/8/87	CZ-2C	Re-entry-type remote sensing satellite	1 820	175	489	63	91	Fallen to earth
19	9/9/87	CZ-2C	Re-entry-type remote sensing satellite	2 100	205	315	63	90	Fallen to earth
20	7/3/88	CZ-3	Operational communications satellite	1 024	200	35 973	31.1	635	
21	5/8/88	CZ-2C	Re-entry-type remote sensing satellite	2 100	175	400	63	90	Fallen to earth
22	7/9/88	CZ-4(A)	Fengyun-1 meteorological satellite	780	883	918.4	99.2	103	
23	22/12/88	CZ-3	Operational communications satellite	1 024	200	35 973	31.1	635	
24	4/2/90	CZ-3	Operational communications satellite	1 024	200	35 973	31.1	635	

TABLE 3

STATISTICS ON OBJECTS IN ORBIT FROM MAJOR LAUNCHING STATES

	Number of payloads (pieces)	Percentage (%)	Number of fragments (pieces)	Percentage (%)	Total (pieces)	Percentage (%)
ESA	16	0.9	461	8.5	477	6.6
France	15	0.3	25	0.5	40	0.6
Japan	34	1.9	47	0.8	81	1.1
USA	535	30.1	2 622	48.5	3 157	43.9
USSR	1 073	60.4	2 241	41.5	3 314	46.1
Other States	104	5.9	11	0.3	115	1.7
TOTAL	1 777	100	5 407	100	7 184	100

DENMARK

[Original: English]

No research on space debris is taking place in Denmark. However, being a member of the European Space Agency (ESA), Denmark is involved in and supports the activities of ESA in the field of research on space debris.

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COMMITTEE ON THE PEACEFUL USES
OF OUTER SPACE

NATIONAL RESEARCH ON THE QUESTION OF SPACE DEBRIS

Note by the Secretariat

Addendum

The present document contains information provided in replies received from Member States up to 25 February 1992.

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CZECHOSLOVAKIA

[Original: English]

1. Definition of space debris

The meaning of the word "debris" is equivalent to that of "fragments". Its main attribute in our case, is inactive and not serving any purpose anymore. In authoritative studies by the European Space Agency (November 1988), by the Office of Technology Assessment of the United States Congress (September 1990) and by the International Astronautical Federation and COSPAR for the United Nations Committee on the Peaceful Uses of Outer Space (December 1988) the meaning of space debris has been extended to all useless objects in space, irrespective of size. It covers objects of all sizes, from large inactive satellites or burnt out rockets, to freely flying covers, nuts and bolts, down to objects of a fraction of a millimetre, such as flakes of paint. Particles of molecular or atomic sizes are not, in general, referred to as space debris.

An attempt at a precise definition was made at the meeting of the Ad Hoc Group on Space Debris at the IAF Congress in Montreal in 1991:

> "Space debris" or briefly "debris" are all manmade objects launched into space and fragments thereof which will not now or in the future serve a useful purpose. The term includes all such objects which survived the passage through the Earth atmosphere. The term "space debris" does not include natural objects such as meteoroids.

The term "space debris" is sometimes qualified. Thus "orbital debris" refers to debris in orbit, while "re-entering debris" means space debris re-entering the dense layers of the atmosphere or impacting on the ground or on the surface of the ocean. It is conceivable that in the future the term "interplanetary debris" will be used to indicate debris which are not in Earth orbit but in interplanetary space. "Trackable debris" means debris which are large enough to be detected and tracked by present radars and telescopes and which can be attributed to a specific launch. "Non-trackable debris" are debris too small or too infrequently observed to enter the category "trackable". The limiting size of trackable debris depends on the reflecting properties of the surface of the particular object. It is approximately 10 cm in low orbits and 1 m in the geostationary orbit.

Instruments of international law of outer space do not know the term or concept of "space debris". Many references can be found to "space objects" or to "objects launched into outer space" which seem to refer to the same concept. They are not natural objects but man-made. "Space objects" include the "component parts of a space object as well as its launch vehicle and its parts". Officially, the relation between "space objects" in the legal sense and "space debris" in the scientific sense has not been established. Some experts in space law are inclined to count space debris as space objects but

others are of the opinion that space objects have been launched with a certain purpose in mind and that space debris do not fulfil that purpose anymore, and that therefore space debris are not "space objects" in the legal sense. The question thus remains whether or not space debris enjoy the protection of space law, in particular of the Outer Space Treaty, article VIII. According to that article, space objects remain under the jurisdiction and control of the launching country and their ownership is not affected by their presence in outer space, on a celestial body or by their return to Earth. Upon request they have to be returned to the launching country.

2. Format of the discussions

The discussions which inevitably will have to take place soon, will take a course determined by the COPUOS and its Subcommittees. In order just to have one of the possibilities before our eyes and not to omit some important aspect, the following overview may serve the purpose:

1. Preventive measures:

   A. Minimizing the amount of debris produced in operational activities;

   B. Averting unintentional explosions;

   C. Regulating intentional explosions;

   D. Maintaining a certain economy of space missions.

2. Active measures:

   A. Removing inactive objects from low orbits;

   B. Removing inactive objects from orbits at intermediate altitudes;

   C. Removing inactive objects from high orbits;

   D. Removing debris by remote action.

3. Passive measures:

   A. Improving the flow of information on trackable space objects;

   B. Avoiding collisions by evasive manoeuvres;

   C. Shielding of spacecraft.

Preventive measures (1) aim at the causes which produce debris. Simple recommendations by the COPUOS would alleviate the situation. Even if such a recommendation is immediately heeded by designers of spacecraft, an interval

of some 6 to 10 years between the design and the launch will elapse before new spacecraft would produce less operational debris than they do at present.

Causes of explosions of some rocket bodies (1B) have already been discovered and procedures were introduced which prevent such unintentional explosions from occurring. A recommendation by COPUOS would certainly support efforts at avoiding these causes. Intentional explosions (1C), if they are necessary at all, should be performed under conditions producing debris with very short lifetimes. There are examples known of explosions leaving no debris.

The principle that space activities have to be performed for the benefit of all countries could be strengthened from an environment-minding point of view. Space missions celebrating or commemorating an event or a person or advertising a product (1D) may do more harm to the environment than good to the intended audience. The question may be addressed of what constitutes the benefit of mankind in this context.

Active measures (2) deal with removing of inactive objects from orbit. There are different methods depending on the altitude of the relevant orbit. In low orbits an object can be sufficiently decelerated by an inflated balloon. At higher orbits, a braking rocket pulse might be needed while in high orbits, such as the geostationary orbit, a reorbiting into disposal orbits beyond the belt of active satellites is the most economical solution. All these measures assume that the method of removal or disposal was decided upon before the launch and that the relevant devices are available on board the spacecraft. Some designers of spacecraft use such or similar measures but a systematic application of these measures will also require several years before they become effective.

Space debris and inactive satellites which are already in orbit can be removed either by direct contact or by remote action. Direct contact, in case it is permitted under space law, requires a spacecraft capable of collecting unwanted objects. This method may be used in rare cases of very valuable inactive satellites but would not be economical for small or worthless pieces of hardware. In the latter case (2D) remote action may have to be resorted to. A few papers on the subject already appeared in literature but some encouragement by a recommendation of the COPUOS would certainly speed up research of such methods.

From among the passive measures, the avoiding of collisions by evasive manoeuvres and the shielding of spacecraft are within the competence of launching and operating agencies. Possibly no international action is necessary. They have been listed here only for the sake of completeness.

The improving of the flow of information on trackable objects is the most important measure in this category. It requires a solution on an international basis. Information on the number, size, location and motion of space objects is essential for the protection of active spacecraft as well as for the application of any method of removal of unwanted objects. The only

intergovernmental source of information is the United Nations Register based on launching announcements by Governments made in conformity with the Registration Convention. The Register is, however, incomplete, the information becomes available far too late and the data in the Register are insufficient for computing positions and motions of space objects. A new system, possibly based on one or more available national systems, providing timely data for all trackable objects, would be extremely useful. A proposal for such a system might be discussed in the COPUOS and its Subcommittees, perhaps with the result that a launching agency, or a non-governmental organization, such as the IAF or COSPAR, assume the responsibility for collecting and disseminating such information to interested users.

GERMANY

[Original: English]

Space debris: review of work done in Germany

Introduction

The scientific/technical analyses of space debris problems were continued in Germany in 1991 (for 1990, see working paper continued in document A/AC.105/C.1/L.170), mainly at the Institute for Space Flight Technology and Nuclear Reactor Technology of the Technical University of Braunschweig (IFRR/TUBS) under contract from the German Space Agency (DARA). Some work was also done in cooperation with the companies DASA/ERNO and Jenoptik.

Another DARA contract was signed in 1990 with the Research Establishment for Applied Science (FGAN) to investigate physical characteristics of selected debris by use of radar data. The present paper provides a review of current work and the main results achieved.

I. SPACE DEBRIS MODELLING

Modelling of the space debris environment is essential for several reasons:

- To obtain knowledge of the population of non-trackable small objects (below 10 cm) and

- For all simulations of the possible further evolution of the environment, which have to serve as a basis for discussions of necessary changes in future space flight policies.

Within the scope of the ongoing research work, several areas have been identified containing uncertainties and weaknesses as to the basic assumptions of space debris modelling, e.g. the mass and the area-to-mass ratio

distributions of the fragments generated by explosions and collisions in Earth orbits. The influence of possible uncertain factors on the modelling results is being evaluated to assess the reliability of the modelling results. Further experiments in explosion and collision fragmentation are urgently needed, in addition to further research work in the field of modelling, to reduce the uncertain factors and hence to increase the reliability of the modelling results.

II. MODELLING OF SMALL PARTICLES IN THE MILLIMETRE AND 0.1 MILLIMETRE RANGE

The small particle debris flux reached today corresponds to about 5 impact/m^2 per year of particles larger than 0.1 millimetre at altitudes of 400 to 500 km.

This estimation is based upon the examination of material returned from space. Materials from the Solar Max satellite were brought back in 1984 and have been examined to determine the debris flux. The Long Duration Exposure Facility (LDEF) was recovered in January 1990 and is being studied. Preliminary results can be found in several publications, see [11], [12] and [13].

Both the Solar Max data and the LDEF data indicate this fairly high flux value of 0.1 millimetre debris. Since LDEF was returned nearly six years later than materials from Solar Max, this flux seems to be steady over a period of time. As these small particles have only a short orbital lifetime due to atmospheric drag, the continuous flux of small debris must have been produced by a steady process.

The earlier assumption [10] that the small particles in this size range would mainly be generated by collisions in space cannot explain this phenomenon because, fortunately, a steady process of repeated collisions has not yet started.

In the current model of IFRR/TUBS, not only collisions but also high-intensity explosions are taken into account. In the period from 1968 to 1989, 29 explosions in space are classified as being of high intensity. With 2 additional collisions, the 31 breakups are distributed over a period of time, in a manner that indicates a steady process generating small debris.

Based on numerical simulations of the 31 breakups, two databases for the millimetre and the 0.1 millimetre range, respectively, have been established. The millimetre database represents 100 million objects while the 0.1 millimetre database covers 80,000 million objects. To make computer simulation possible, only 84,000 sample objects have been selected for each database. The selection is conducted in such a way that the distributions of mass, semi-major axis and eccentricity are statistically represented.

These databases have been applied to predict the debris flux on LDEF [14], and the modelling results correspend positively with the observed data.

III. SPACE DEBRIS MEASUREMENTS

During 1991 a study was initiated to examine the capabilities of optical space debris observation. The main goal of this study is a concept that would permit the existing data gap [9] of space debris in the millimetre- to decimetre-size regime to be closed. Both ground-based and space-based telescopes operating in the visible and infrared wavelengths have been analysed, taking into consideration a number of relevant detection scenarios.

During the study, attention was focused primarily on two orbital altitude regions, i.e. 350-500 km (where manned space flight is performed) and the region of 800-1,000 km altitude, which is characterized by the highest object density. The results of the study so far can be summarized as follows:

- Optical detection and measurements of space debris in the above-mentioned altitude regions could make a substantial contribution to the urgently needed verification of space debris modelling.

- In the case of space-based measurements, an elliptical, sun-synchronous sensor orbit (e.g. 500 km x 900 km) operating at the day-night terminator seems to be appropriate (optimal object illumination, detection 24 hours a day).

- In the case of ground-based telescopes (modified) existing systems should be used.

- Concepts for data evaluation and space debris model upgrade are available.

- The technical concepts (instrumentation, infrastructure) are feasible, the anticipated performance (number of detections, detection rate, optical range etc.) meets the requirements.

IV. COLLISION CHAIN REACTION EFFECTS

At present, the space debris collision risk is probably dominated by fragments from the explosion of payloads and rocket upper stages in Earth orbits. In the future, interactive collisions between objects in Earth orbits may become the main source for the generation of fragments.

The total risk for a collision among an assumed current population of 85,000 objects above 1 cm is about 45 per cent annually. The collision risk estimation for the total destruction of the target object is presently in the order of about 7 per cent annually [1].

The larger fragments generated by such collisions should lead to the formation of an artificial debris belt as a result of a chain reaction. Analysis has shown that the current population in higher altitudes has

possibly already exceeded the critical level [1]-[5]. These results are consistent with investigations performed by NASA using totally different approaches [6].

Basically, the increase in collision risk will be proportional to the square of the number of objects in Earth orbits. But the larger objects, as the potential sources for the generation of a large number of collision fragments, are of crucial importance. Hence, it is important that the population of larger objects be limited within the next few decades. Therefore it is necessary to introduce fundamental changes in the way space flight activities are carried out: all objects brought into higher Earth orbits, where there is no self-cleaning effect of the Earth atmosphere, must be actively removed after the end of their mission, preferably by a propulsive deorbit device.

If it is not possible to limit the population of large objects in time, i.e. within the next 10 to 30 years, the only way of preventing a chain reaction after the critical population level has been exceeded is to reduce the population of large objects by active removal [7], [8] (see following chapter).

V. LIMITATION OF THE POPULATION BY ACTIVE REMOVAL

As has been discussed in the previous chapter, the debris population has to be limited to an uncritical level as far as fragment generation due to collisions is concerned. Preventive measures, which are preferable, have already been described in detail in document A/AC.105/C.1/L.170. Another option for limiting the population is active removal, which is much more difficult and expensive. However, if preventive measures are not sufficient or if they are not introduced in time, active removal will be the only way to avoid a collision chain reaction.

Active removal is only economical

- for larger objects, because they are the potential sources for the generation of a large number of fragments following collisions;

- at altitudes between 700 and 2,000 km, where the chain reaction will be triggered and the objects have very long lifetimes;

- on a large scale (several thousands); otherwise there will be no appreciable effect.

A fundamentally new strategy for economical removal with the help of space tethers called TERESA (TEthered REmover SAtellite) is under investigation [7], [8]. This strategy is feasible through the use of techniques expected to be available in the near future.

VI. SHIELDING AND IMPACT ANALYSES

While the impact risk of centimetre-sized particles is still minor for small satellites and short mission times, it becomes unacceptably high for large manned vehicles and long mission durations, such as the pressurized modules of space stations. These have to be protected against debris smaller than a few centimetres by heavy shielding.

In Germany there are many activities in the field of meteorite/debris protection measures. Studies of concepts for meteorite and debris protection systems for manned spacecraft (e.g. COLUMBUS) are performed under ESA contract by MBB/ERNO. These studies include hypervelocity impact testing (Ernst-Mach-Institut, Freiburg, Batelle Frankfurt) of several shielding configurations, as well as the development of corresponding design tools.

In IFRR/TUBS, double wall shielding concepts are being analysed and a computer code, named DAMAGE, has been developed. By means of the DAMAGE code the shielding can be designed to meet the required safety level. Also, spectral analysis of penetration flux versus impact velocity or particle diameter can be conducted, which is very effective for the verification of existing penetration functions.

VII. PHYSICAL CHARACTERISTICS OF ORBITAL DEBRIS

As mentioned above, explosions and collisions in space are the major source for orbital debris. The debris fragments pose a hazard to large spacecraft designed to operate for long periods of time. A contract from DARA was signed with the Research Establishment for Applied Science (FGAN) in 1990 to investigate physical characteristics of selected space debris by use of radar data. The objective of a corresponding NASA/FGAN joint research investigation is to characterize and compare debris shapes, sizes, intrinsic motion, masses, and orbital lifetime from different explosions.

FGAN radar systems (narrowband as well as high-resolution radars) have been used to measure a collection of 16 different larger debris objects. Narrowband radar signatures were analysed and radar images have been computed [15], [16] to get first results about shape, size, attitude, and mass. Methods to assess orbital lifetime, ballistic coefficient, and drag factors of space objects were developed. They have been tested with FGAN radar data stemming from observations of decaying spacecraft [17], [18], [19].

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UKRAINE

[Original: Russian]

Although to date the Ukraine has not conducted scientific research on space debris, Ukrainian scientific institutions possess a number of methods of locating, and determining the exact coordinates of, large remains of space objects.

The Main Astronomical Observatory of the Academy of Sciences of the Ukraine has developed, prepared and put into operation on a wide-angle astronomical camera special equipment for observing geostationary satellites capable of determining the coordinates of objects with a brightness equal to or greater than stellar magnitude 14 to an accuracy of 0.3-0.6 arc-seconds.

An improved set of equipment has been designed, which would make it possible to locate fragments of space objects ranging in size from 10 cm and above.

In cooperation with a number of research institutes, the Main Astronomical Observatory of the Academy of Sciences of the Ukraine developed and tested an infrared television system operating in atmospheric transmission windows of 2.2 and 3.5 micrometres. The use of such equipment mounted on ground-based telescopes makes it possible to locate large fragments of structures of spacecraft in outer space.

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NATIONAL RESEARCH ON THE QUESTION OF SPACE DEBRIS

Note by the Secretariat

Addendum

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RUSSIAN FEDERATION

[Original: Russian]

The littering of circumterrestrial space with fragments of space technology is a global problem that affects the interests of many countries. There are currently, in low-Earth orbit, approximately 7,000 artificial objects (non-operational space vehicles, rocket stages, large structural debris), which are tracked by space monitoring means, as well as tens and hundreds of thousands of fragments of various dimensions. The annual growth of fragments and man-made particulates in orbit is approximately 4-5 per cent.

The largest concentration of space debris is observed at altitudes of 800, 1,000 and 1,500 km at inclinations ranging from 60 to 100 degrees.

At the existing rate of growth of debris in circumterrestrial space, in 20 to 30 years access to outer space will be considerably more difficult.

If space debris continues to increase at the current rate, the probability of collision with dangerous debris in low orbits will double or triple every decade.

The assessment of the current accumulation of space debris in low-Earth orbits and its predicted increase point to the need to take timely technical and legal measures to reduce the growth rate of such debris.

Technical measures include:

- Reducing the number of space vehicles launched while increasing their orbital lifetime and integrating their tasks;

- Refraining from destroying objects in orbit, in particular the deliberate destruction of a spacecraft;

- Excluding or reducing to a minimum the number of rocket stages and elements of space vehicles that separate in orbit;

- Non-use in outer space of propulsion systems using fuels that produce solid particulates during combustion;

- Use of materials and shields on space objects that are highly resistant to erosion due to the effects of circumterrestrial space;

- Controlled removal from working orbit of space vehicles that have ended their operational life, and their placement into the dense layers of the atmosphere or a graveyard orbit;

- Development of space launch programmes in which the last stage of the launch vehicle does not go into orbit (unbounded orbit launch) with the subsequent completion of the spacecraft's insertion into orbit using an apogee boost engine;

- Maximum use in future of space shuttle systems.

The preparation of legal norms and provisions should focus not so much on measures that restrict the use of space technology as on the improvement of such technology with a view to preventing the further accumulation of space debris.

The solution of this problem will require international cooperation.

Following are specific proposals for such cooperation:

1. Agreement on methods of cataloguing space objects, systematic exchange of reports on the movement of satellites, including information on objects still in orbit or which have left their orbits or have exploded;

2. Creation of a common database on objects presenting a high degree of risk (large satellites approaching the upper atmosphere, debris from explosions, objects that have gone out of control, and so on);

3. Exchange of samples that have been exposed to the effects of microfragments in outer space, as well as the results of their analysis. The conduct on board the Mir orbital station of a joint experiment involving the cataloguing of man-made particulates in outer space;

4. Modelling of the distribution of space debris in circumterrestrial space, the assessment and prediction of the risk of collision between objects of various descriptions. Comparison of the results of modelling;

5. Elaboration of standards to be met by the space industry with a view to reducing or preventing the further accumulation of space debris;

6. Development of a legal basis for regulating space activities with respect to the problem of space debris.

The study of various aspects of the problem of space debris was begun in the Russian Federation at the end of the 1970s. In recent years, research on debris in circumterrestrial space has become routine and comprehensive and includes the following basic areas:

1. Study of the origin of space debris and its accumulation in outer space, and elaboration of measures for its reduction;

2. Study of the physico-chemical interaction of space debris and space vehicles;

3. Data monitoring of the space debris environment through the observation of debris, study of the physical processes resulting in the formation of clusters of debris and the nature of their movement, and elaboration of measures to ensure the safety of space flight;

4. Solution of the scientific and technical problem of increasing the operational life of space vehicles up to 7-10 years;

5. Prevention of the disposal in outer space of structural elements of a new generation of spacecraft, and the return to Earth or combustion in the atmosphere of stages of launch vehicles;

6. Development of a system of basic data and a mathematical model of the evolution of space debris, the adequacy of which will be verified during space experiments, including the Obzor space experiment planned for 1992-1994;

7. Comprehensive research on the effects of space debris on space objects, modelling of the probability of the hypervelocity collision of man-made objects with space objects, and the search for ways and means of disposing of space debris.

A comparison of Russian, American and European data on the origin and accumulation of space debris in circumterrestrial space, carried out in the Russian Federation, showed that the three sources of data were in substantial agreement regarding the current level of space debris. At the same time, a certain divergence was noted in Russian and foreign assessments of the percentage of overall space debris caused by the explosion of space and launch vehicles produced by Russian space technology.

In January and February 1991, work on the monitoring of the last stage of the flight of Salyut 7/Cosmos-1686 and its re-entry was carried out. Such work received much international attention and involved, for the first time, the direct cooperation of Russian, American and European specialists in space monitoring.

A special scientific seminar organized by the European Space Agency was held at Darmstadt, Germany, from 8 to 14 April 1991. At the seminar, a Russian specialist reported on the results of the experimental testing of highly precise methods of predicting the movement of passive cosmic bodies (space debris). Russian specialists won high acclaim at the seminar for their accuracy in predicting the region and time of re-entry of debris from the complex.

SENEGAL

[Original: French]

To date, Senegal has not carried out any research in this area. However, this area of activity comes within the scope of the Institute of Applied Nuclear Technology of the Cheikh Anta Diop University of Dakar.